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Strategic Public Health Concerns Resulting From Cognitive Insult on the Modern Battlefield and Cognitive Readiness

by
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Disclaimer

Introduction

In the modern age of warfare the military member's central nervous systems (CNS) are under significant physical and cognitive assault as a result of operational engagement tactics of the US military and its enemies. The spectrum of CNS-mediated conditions our soldiers, sailors, and Airmen are exposed to in-theater, range from effects that may be short-term and recoverable, such as fatigue, to long-term and non-recoverable, such as traumatic brain injury (TBI). The purpose of this research article is to define the spectrum of strategic public health conditions that encompass cognitive insult and examine an emerging CNS exploitation risk. In addition to an examination of the spectrum of cognitive insult, a review of three emerging strategies to identify and ameliorate the long-term cognitive insults will be explored.

The strategic public health issue on the physical end of the insult spectrum is TBI. This insult is generally caused by some type of trauma in the CNS and is seen frequently in military personnel exposed to an explosive force. On the cognitive insult end of the spectrum are conditions such as fatigue (chronic and short-term) induced through long, counter circadian rhythmicity operations that force long periods of continuous wakefulness. This paper will examine fatigue and the countermeasure strategies employed by the US military. In addition to these operational strategic public health risks, a series of future battlefield-related risks are/will receive attention in the near future. The risk area examined in this paper is battlefield or occupational radio frequency (RF) exposure and the subsequent effects these relatively unexplored advances in technology may have on the CNS. The CNS and peripheral nervous system (PNS) may be susceptible to manipulation by RF to achieve operational effects. The Active Denial System (ADS) is a non-lethal weapon system that has already been employed to exploit pain sensitivity to determine intent of a population of people.

Strategies are emerging to ameliorate the impact of cognitive insult. Re-emergence of the concept of cognitive readiness suggests soldiers, sailors, marines, and Airmen may be prepared prior to combat experience to protect their CNS against insult, but also protect the desired behavior DoD has attempted to train and educate in response to a combat scenario. A proposed model is used to understand how cognitive readiness drives the relationship between *Action* and *Training*, with the ultimate goal to produce DoD members that act in a predictable and rational way. By preparing the CNS prior to combat operations, DoD prepares its members to interpret information correctly and execute behavior that is effective, even if the scenario is unpredicted.

Traumatic Brain Injury

Since the employment of artillery, then mines, and now improvised explosive devices soldiers have been confronted with explosive devices that can kill in multiple ways. However, the techniques employed by conventional war makers and insurgents in Iraq and Afghanistan have presented operational decision makers with a new set of strategic public health problems as a result of how the explosive devices are utilized. The method of injury/death can be divided into two categories, the first being the effects caused by the heat energy released by the explosion. Due to the incineration of the human body there is no purpose in investigating TBI in this category. The second is the physical effects of the explosion or blast wave, which does not immediately kill, but does expose the soldier to tremendous physical forces. This category can be subdivided into three-levels of analysis.[1]

The first level is “primary blast induced neurotrauma”, which is characterized by the effects of the blast wave itself. The blast wave is an extremely high pressure, high velocity wave that impacts the human body. There is no direct impact of material with the body in this level of

exposure. The transfer of the kinetic energy in the wave to the human body causes abrupt acceleration.

The "secondary blast induced neurotrauma" involves the projectiles associated with the explosion of the device. This material has the ability to penetrate the skull and impact the CNS through physical destruction of the neural tissue. Hemorrhaging of blood vessels that supply the CNS and physical destruction of the CNS is the immediate medical concern. Furthermore, this insult to the integrity of the environment of the CNS leaves the soldier susceptible to infection if the wound is not immediately cared for in a hospital.

The "tertiary blast induced neurotrauma" involves collision with material that is stationary. The neurotrauma seen at this level is the physical contact of the head with an object that is denser and thus, causes rapid deceleration and similar injury as the primary blast model. The physical contact of the cranium with the denser material causes neural tissue disruption and vascular disruption leading to immediate physical damage and long-term effects.

The concept of TBI is relatively new to the medical professional charged with caring for injured soldiers. There are battlefield characteristics that are driving the occurrences of these injuries. DoD data indicates 73% of all OEF/OIF casualties resulted from explosions.[2] Soldiers exposed to explosions are surviving due to the advances in body armor protection. Furthermore, protection from vehicles is enhancing survivability from the incineration of explosion discussed above. However, enhanced initial survivability is accelerating the occurrence of secondary injury effects. As an example, the data supporting body armor protection is in question. Data suggests body armor may actually enhance primary blast effects on the body.[3] Despite the conflicting data, it should be assumed that soldiers that would normally be killed due to proximity to the explosive are likely not dying, which is increasing the secondary blast wave mediated effects.

These effects are primarily manifested through damage to the CNS. From January 2003 to February 2005, 59% of patients admitted to Walter Reed Army Medical Center showed symptoms of TBI.[4] From a strategic public health perspective, damage to the CNS, or conversely protection of the CNS is paramount.

Tissues such as the human brain possess significant inertia, which resists the acceleration imposed by the primary/tertiary blast effect, leading to sheering forces in the CNS. The types of injury seen include tissue-level disruption, neuronal connectivity disruption, and vascular damage leading to edema or swelling in the cranial space. The acute vascular damage or hemorrhage also imposes significant concern because CNS tissue dies quickly undergoes ischemia without blood supply. There are immediate consequences and longer-term consequences of these effects. Immediate consequences are manifested in physical disruption of the neurocircuitry of the CNS. Large bundles of neurons compose the white matter of the CNS. The white matter is distinct from the grey matter as these bundles possess myelinated axons, giving it a white appearance. The intense sheering forces tear at these fibers, literally pulling the neuronal connects apart. The effects of this type of injury manifest as unconsciousness, nausea, memory loss, confusion, or dizziness. The physical forces of the blast causing neuronal disruption lead to inflammatory responses in the CNS. The sites of physical damage and material released by damaged neurons recruit the support cell types found in the CNS, primarily led by the microglia and astrocytes. These cells begin releasing cytokines into the neuropil, the space between neurons and support cells in the grey matter. This literally stimulates a storm of activity, some of which is neuroprotective and neurotoxic. The behavioral manifestations of these events may be loss of consciousness, lack of concentration, loss of memory, and disruption to normal CNS behavior regulation. It’s important to recognize that all of this damage may occur without

an outward appearance of physical injury. This is one of the reasons TBI is so dangerous. The longer-term consequences have received little investigation, but the damage to the CNS likely causes long-term neuroendocrine-immune system activation leading to massive inflammation cascaded in the CNS which may cause death sometime after the initial blast or even lead to CNS effects that may not manifest for years.[5] The connection to post traumatic stress disorder (PTSD) is currently receiving significant scientific examination. In one study, 40% of soldiers, reported to have lost consciousness during an explosion, meet subsequent criteria for diagnosed PTSD.[6] The biological explanation for this connection is still inconclusive, but hypotheses suggest the extreme stresses associated with explosive events drive hyper-activation of the hypothalamic-pituitary-adrenal axis (stress neurocircuitry), long-term neuro-immune activity, and sleep disruption.[7] Additional public health concerns associated with CNS injury include significant depression, drug abuse, and family mental or physical abuse. Even more alarming, data emerging from sports physiologists examining athletes who engaged in full contact sports, suggests athletes that have sustained concussion up to 30 years ago display memory deficit, reaction time to stimuli deficit, and reduced movement velocity.[8] It is also believed Alzheimer's and Parkinson's disease are the behavioral manifestation of mild, long-term CNS inflammation leading to neurotoxicity. Additional studies will be needed to elucidate a reliable link to occurrence of Alzheimer's and Parkinson's disease in athletes and soldiers that have sustained repeated concussion.

Cognitive Fatigue

The modern Airman is increasingly faced with operational-induced, cognitive challenges that are unprecedented. The operational requirements imposed on USAF Airmen, as mission sets

become more diverse and challenging are pushing their cognitive capabilities to previously unknown limits. The cognitive abilities of our Airmen are arguably their greatest asset as the culture of the USAF is one of technology, decision making, and application of airpower in dynamic environments.[9] As a result of 36-hour B-2 missions, 70-hour special operations missions directing aircraft, 12-hour shifts of monitoring full motion video data, and 12-hour loiter missions in F-16 fighters, and all while operating in opposition to circadian rhythmicity, our Airmen are under operational cognitive attack.

The Air Force Research Laboratory (AFRL) has conducted research to understand how fatigue (or sustained wakefulness) has impacted operational decision making and performance in aviators.[10] It is well known that sustained wakefulness causes significant decrement in cognitive performance. In fact, simple test batteries are the gold-standard for documenting cognitive disruption as fatigue occurs. In the Automated Neurophysiological Assessment Metrics (ANAM) and Psychomotor Vigilance Test (PVT) subjects perform mathematical and grammatical reasoning problems and are evaluated on reaction time and accuracy of their responses. The relationship between continuous wakefulness and performance is shown in figure 1.[11] This relationship demonstrates the rate at which cognitive function decreases as a percent of effectiveness. This figure puts into context the operational impact of operating on minimal sleep or no sleep for 20-50 hours, a common

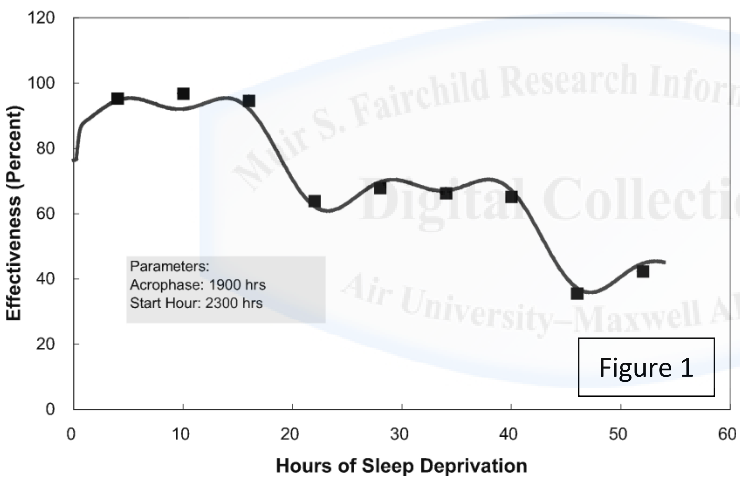


Figure 1

occurrence in modern military operational scenarios. The decline quickly reaches 60% effective and drops to below 40% at 45 hours. However, there are scientifically proven strategies that counter the effects of sleep deprivation. The US Army has invested heavily in research in caffeine. Harris Lieberman at the Military Nutrition Division at the US Army Institute of Environmental Medicine has conducted extensive research in an effort to understand the operational impact of caffeine.[12] Lieberman has demonstrated that in dosages of 100 to 600 mg caffeine is a reliable psychoactive drug to maintain performance in militarily relevant scenarios, including shooting and "Hell Week" performance in US Navy Seal candidates. The US Army has partnered with Wrigley's to produce "Stay Alert Gum". This gum provides 100 mg of caffeine per stick.[13] Despite the impact of caffeine on maintaining cognitive performance in operators, the US Air Force has chosen to pursue pharmaceutical grade psychoactive drugs to maintain wakefulness, particularly in aircrew. In figure 2 the CNS mechanism of dexamphetamine ("go-pill") is depicted.[14] The drug binds the re-uptake mechanism of noradrenaline, which maintains an elevated concentration of the neurotransmitter in the synaptic cleft, thereby enhancing continued chemical signaling on the post-synaptic neuron. The behavioral manifestation of the blockade of the reuptake mechanism is maintained cognitive performance despite the cognitive impact of sustained wakefulness. This effect was demonstrated by John Caldwell, while at the US Army Aeromedical Research

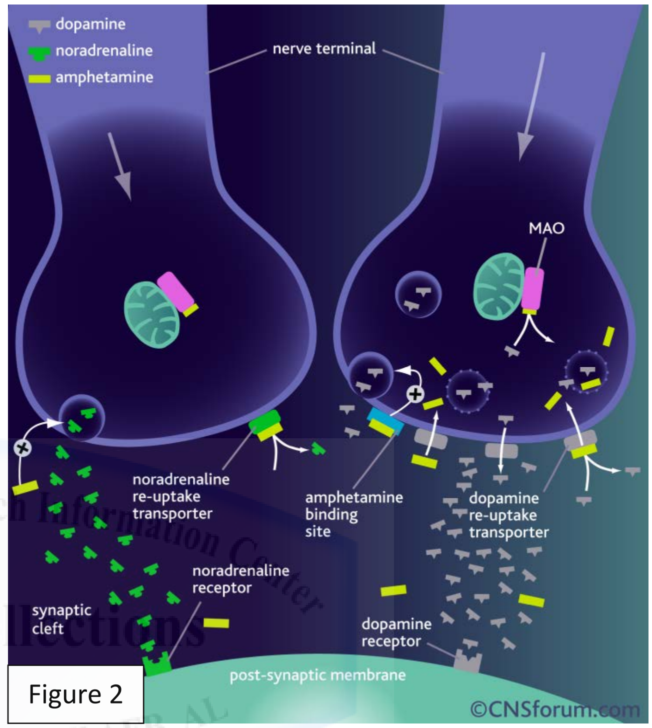


Figure 2

Laboratory at Ft. Rucker.[15] In this study 6 UH-60 helicopter pilots were kept awake for 64 hours and evaluated utilizing the laboratory gold-standard assessment tools, but also were evaluated in the cockpit while operating the UH-60. 5 mg of dexamphetamine or placebo were given to pilots over the course of the study in regular intervals. Utilizing various flight performance measures the pilots were evaluated using baseline data collected while in a rested state. As anticipated, flight performance decreased by 25% relative to baseline performance over the course of the sleep deprivation. Dexamphetamine rescued the decrement in performance and showed a significant drug effect over time. The unfortunate side effect is depicted in the second neuron from figure 2. Dexamphetamine blocks the re-uptake mechanism of dopamine. Dopamine is a neurotransmitter implicated in signaling the pleasure or hedonics of behavior. In virtually all known substances of abuse or those that become addictive the dopaminergic neurocircuitry in the CNS is manipulated to facilitate addiction. Dexamphetamine is no different and this has led the USAF to examine other strategies to maintain wakefulness.

Research at the Air Force Research Laboratory (AFRL), Brooks City-Base, Texas demonstrated how extremely well trained special tactics ground operators can function despite effects of fatigue. However, even this population of special operators required access to fatigue countermeasures that for operational reasons could not be dexamphetamine. This AFRL study employed an 88-hour continuous wakefulness paradigm to evaluate the efficacy of Modafinil.[16] Modafinil is a drug designed to maintain wakefulness in people that have clinically diagnosed narcolepsy or require a pharmaceutical-level aid to maintain wakefulness. It is marketed under the name Provigil. The drug was evaluated in clinical trials and brought to market by Cephalon.[17] To date there is no definitive mechanism of action in the CNS, however, the drug is believed to bind the alpha-1 adrenergic receptor and act in a similar manner as norepinephrine.

Modafinil is a Class IV controlled substance as defined by the Controlled Substance Act, 1970.[18] This means Modafinil has a medical use and a low potential for abuse. In comparison to heroine (diacetylmorphine), a Class I controlled substance, there is no medically defined use and the potential for abuse is extremely high. The classification of Modafinil as a Class IV controlled substance and the limited side effects noted in clinical trials has justified a military application in light of the significant problems associated with dexamphetamine, the traditionally prescribed "go-pill".[19]

In this study an 88-hour continuous wakefulness paradigm was determined to be a "normal" mission profile for these highly trained operators. The study was designed to evaluate multiple cognitive performance variables, including assessments routinely conducted in the laboratory (ex. PVT and ANAM) and assessments special operators are required to perform in the field. Dependent variables included tasks that require high cognitive acuity such as, radio protocol, weapon disassembly/assembly, and medical procedures. The tasks also included physical tasks including, fitness tests, obstacle courses, and standing jump. The design of the study was unprecedented, as this was a double-blind placebo-controlled crossover analysis. The subjects repeated the 88-hour experimental design twice, once under the influence of drug and again after administration of placebo. And each subject was blind to which treatment they were given. The administration of the drug was every 8 hours and the dose was 100 mg for a total of 300 mg/day.

The results of the data analyses revealed the decrement of performance over time without sleep. However, the results departed from previous laboratory data because Modafinil only was able to significantly maintain performance in the mathematical processing tests, such as PVT. Additionally, Modafinil positively affected a subjective analysis designed to assess self-reported

vigor. No other data were significantly different from the placebo. One other interesting subjective result indicated Modafinil was detectable by the participants. Eleven of the twelve participants correctly predicted their treatment and described it as “keeps you mentally focused when it’s hard to stay focused” and “improved mental alertness of operators engaged in surge operations”.[20] It was particularly interesting that the participants felt the dose was too weak, relative to the dosing of dexamphetamine that all subjects had experience with. The operators wanted to feel the surge in heart rate and blood pressure to validate the presence of a wakefulness aid.

These results led to valuable conclusions about cognitive fatigue and Modafinil. Highly trained operators that are kept awake for 88 hours are still able to perform the tasks that they have spent a tremendous amount of time training to perform. It could also be argued that this population has self-selected for fatigue-resistant individuals. Thus, in this population there isn’t much drug efficacy space to demonstrate. Modafinil is not a performance enhancer. Rather it maintains the level of performance despite continued wakefulness. Modafinil did maintain performance in the mathematical performance tasks suggesting that simple cognitive reasoning is susceptible to cognitive fatigue and that in an operations requiring reasoning, independent of training, Modafinil is suitable to protect decision-making and cognitive processing.

This begs the question regarding the drug’s efficacy in acute sleep deprivation paradigms for operators that have less training and less controlled medical guidance. Furthermore, what if any effects can the drug elicit in chronically sleep deprived operators as operators struggle to perform over days or weeks of minimal sleep? As researchers attempt to understand how cognitive fatigue truly effects military operations, the reliance on non-pharmaceutical aids and

pharmaceutical aids will continue to supplement the well-known decrement in cognitive performance.

RF Battlefield Exploitation

It has been suggested that future wars will be fought over the operational employment of the electromagnetic spectrum, more specifically the range of RF that can be employed operationally to have battlefield effects on the human. The application of Electronic Warfare (EW), and specifically directed energy (DE), on the modern battlefield is published in AF Doctrine Document 2-5.1.

> **Directed Energy (DE) in EW DE is an umbrella term covering technologies that relate to the production of a beam of concentrated electromagnetic energy or atomic or subatomic particles.** Directed energy warfare (DEW) is military action involving the use of DE weapons, devices, and countermeasures to either cause direct damage or destruction of enemy equipment, facilities, and personnel, or to determine, exploit, reduce, or prevent hostile use of the EM spectrum through damage, destruction, and disruption. It also includes actions taken to protect friendly equipment, facilities, and personnel and to retain friendly use of the EM spectrum.[21]

For the purposes of this review, the focus will remain on the impact of DE, on strategic public health and the impact on CNS and PNS biology.

An existing weapon system that produces operational impact, through exploitation of RF and human systems PNS biology, is the Active Denial System (ADS).[22] The ADS is a non-lethal weapon system designed to determine the intent of an individual or a group of people advancing on a position of denial. The ADS produces millimeter waves at 95 GHz with a wavelength of 1/64th of an inch. This means the millimeter wave that is produced will only penetrate that distance into the human body until it is stopped. The device exploits nociceptive pain in the skin to elicit a reflexive action. The skin feels as if it is burning, but there is not sufficient power to

cause burns. The behavioral response to this experience can now be examined for intent regarding movement toward the denied position. If the individual or group continues to advance lethal force may now be the only option, however, in the case of the ADS it was not the first. The ADS is an example of a non-lethal weapons system that exploits RF and the PNS, employed by US Forces. If the US has developed this type of technology its likely US adversaries have also developed technology to achieve similar battlefield gains.

The United States, Russia, and China are at the forefront of the neurophysiological exploitation research effort. Drs. Allen Frey and Ross Adey controversial research into exploitation of cognitive function has received significant public attention, primarily due to the direct application of military employment. Dr. Frey was the first author to publish in the public research community the effects RF can have on CNS tissue.[23] In this research article, Frey discusses the role of pulsed-RF induced "microwave hearing". Frey conducted this research as a result of anecdotal evidence that emerged from WWII given by radar operators exposed to RF frequencies at the low end of the electromagnetic spectrum. The physical effect of this exposure is manifest in a buzz or clicking sound. In that paper Frey makes his claim, "Using extremely low average power densities of electromagnetic energy, the perception of sound was induced in normal and deaf humans. The effect was induced several hundred feet from the antenna the instant the transmitter was turned on, and is a function of carrier frequency and modulation."[24] Guy *et.al.* attempted to understand the bioengineering mechanics of the effect in 1970's. He specifically worked to understand if the RF is directly in the CNS or rather, is the effect a transduction of RF energy to acoustic energy.[25] This neurophysiological understanding of RF was key for the next area of research which centers on the LIDA machine.

The LIDA machine was a device made in Russia that emitted 40MHz pulsed waves.[26]

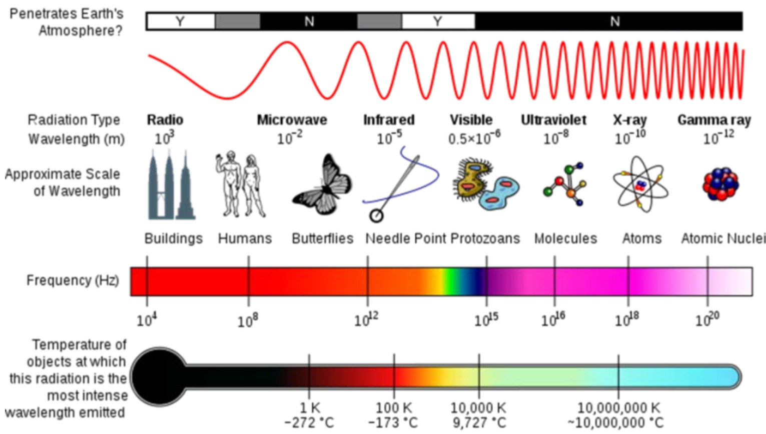


Figure 3

Figure 3 demonstrates the RF frequency spectrum for reference. The Russians reported the devices medical application was RF-induced anesthesia. Adey was given access to the machine through medical exchange and began researching function and effect. The low frequency RF waves were thought to stimulate electromagnetic frequency similar to those endogenously produced by the CNS and produce relaxation and trance. Adey is quoted, “Within a matter of two or three minutes it [cat] is sitting there very quietly…it stays almost as though it were transfixed.” In a statement from Dr. Eldon Byrd, the researcher who funded Adey, the effect is further described, “The Soviets included a picture with the device that showed an entire auditorium full of people asleep with the LIDA on the podium. The LIDA put out an electric field, a magnetic field, light, heat, and sound.”[27] This result is not meant to verify or demonstrate that this device actually can achieve this effect, rather to demonstrate that there is significant interest in the cognitive exploitation of the CNS by the military. Dr. Byrd, ran the Marine Corps Nonlethal Electromagnetic Weapons project from 1980-1983. In a 1997 *US New and World Report* article, he is quoted, “We could put animals into a stupor, we got chick brains-in vitro to dump 80 percent of the natural opioids in their brains.”[28]

The effects on the CNS these low RF fields have on biological tissue have been established as better understanding of the cellular and molecular basis of the CNS is examined

and elucidated. In a civil public health matter, the CNS has been the subject of tremendous research as the modern population is exposed to RF emitters in very close proximity in the form of our cellular telephones. The emerging data are extensive and impactful in the International Arena. The World Health Organization (WHO)/ International Agency for Research on Cancer (IARC) have released guidance that electromagnetic radio frequencies similar to those emitted by cellular telephones are possibly carcinogenic.[29]

Since this area is considered an emerging area of strategic public health, basic biological research is ripe for adaptation to tools of battlefield exploitation. A family of recently discovered proteins in neurons of the retina called Cryptochromes (CRY) is now receiving considerable attention for understanding how low RF fields impact CNS processing. In a recent study published in *Nature* it was shown that CRY2, the protein primarily expressed in humans, functions as a light-sensitive magnetosensor.[30] In this study, researchers used *Drosophila* (fruit fly) genetically engineered to express the human CRY2. Researchers used a behavioral apparatus, commonly referred to as a T-maze, to examine a trained response for reward (sucrose) in an electric-coil-magnetic field. The magnetic field detection by the fly provides directionality for repeated access the reward. The results of the experiments show that in flies engineered to express the human form of CRY, they were able to detect the magnetic field and navigate the T-maze for the reward. An interesting aspect of the result, was that blue light wavelengths (400 nanometers) were required for the fly to navigate the maze. Thus, both light and magnetic fields are required for this family of proteins to respond and direct a very complex behavioral response. The authors conclude, based on evidence from a previous study, that CRY plays a key role in determining circadian rhythmicity and response to low-level magnetic fields.[31] This basic research may be uncovering the neurophysiological molecular underpinnings of Adey's research

in the LIDA machine. While any direct association is extremely pre-mature, the molecular basis for RF-controlled cognitive disruption may lie in an in-depth understanding of the proteins that regulate circadian rhythmicity. While it is equally premature that any nation is examining RF for non-lethal employment, there is DoD-level publications available examining Russian and Chinese capability in this area.[32]

CNS Vulnerability

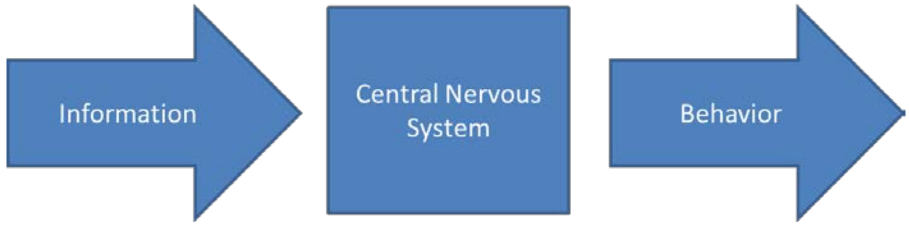
Despite the vulnerability of the CNS to the characteristics of the modern battlefield, there is significant effort from medical and research communities to ameliorate the harmful effects of the battlefield on the CNS. Wakefulness strategies have already been discussed to protect against the cognitive deficit associated with fatigue. Caffeine and Modafinil employment are examples of pharmaceutical strategies that protect cognition, but do not restore normal cognitive function associated with standard sleep patterns. The “magic bullet” from the clinical and research perspective is the pharmaceutical strategy that rescues cognition despite the lack of sleep and erases the sleep debt associated with interrupted sleep patterns or chronic wakefulness. The penultimate is a strategy that generates a sleep bank. Currently, our understanding of the human sleep regulatory mechanism does not suggest a sleep bank can be generated for use at a later date or prior to an impending deficit. Additionally, PTSD and TBI rates have been significantly elevated since the wars in Iraq and Afghanistan. By definition the treatment of PTSD and TBI begin after diagnosis of the condition or the occurrence of the injury. Consequently, treatment may be further complicated by the development of alcoholism, domestic violence, and suicide upon returning from the deployed location.[33] The Marines have begun to educate their leaders on the role of cognitive fatigue on the CNS and decision making.[34] A highly stressed and fatigued

CNS is a vulnerable CNS. Not only is decision making compromised, but the impact of mild TBI and/or the development of PTSD may be enhanced in the CNS that is vulnerable due to chronically elevated levels of stress and fatigue. An Army study revealed soldiers deployed to Iraq displayed persistent memory deficiencies for up to 2 months following redeployment.[35] Interestingly, the study revealed soldiers showed enhanced reaction time compared to non-deployed soldiers. These data demonstrate moderate levels of stress drive neuroplasticity, but chronic, high-levels of stress render the CNS vulnerable to battlefield injury and exploitation. Moreover, even after these soldiers return from the deployed location the CNS remains vulnerable to the development of PTSD.

If the CNS can be better prepared prior to cognitive insult, then resiliency and recovery may be enhanced. Perhaps soldiers, sailors, marines, and Airmen can be trained or at the very least better prepared to deal with the stressors of combat to facilitate cognitive readiness and/or resiliency. We train our soldiers, sailors, marines, and Airmen to be physically prepared to deploy to combat zones; the next logical step in preparedness is cognitive readiness.

Cognitive Readiness

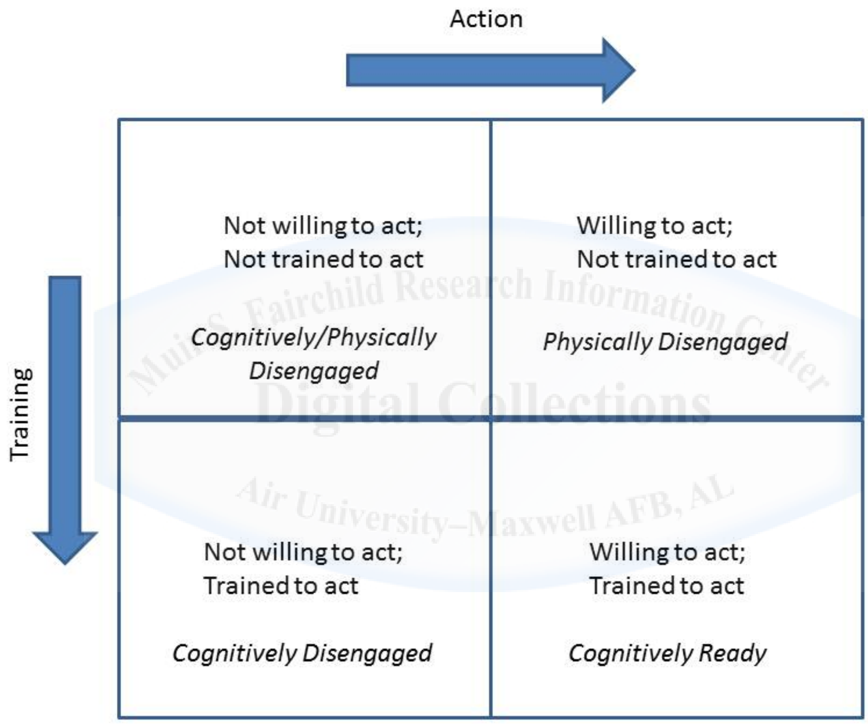
The military operational environment is saturated with ever increasing levels of informational complexity. The DoD is training soldiers, sailors, marines, and Airmen to correctly interpret information and act in accordance with education and training. If this does not occur the consequence is loss of life or loss of high value equipment. Cognitive readiness is a state of being for soldiers, sailors, marines, and Airmen that supports their correct interpretation of environmental stimuli, cognitive analysis, and execution of anticipated and appropriate behavior in response to that environmental stimulus. The model below is an extremely simplified



depiction of this relationship. The CNS relies on the senses to transmit a variety of information types for integration and analysis. The outcome of that extremely complex and not very well understood process is behavior. Understanding, predicting, and reinforcing human behavior in complex military environments is a focus of DoD and other academic researchers.

In an Institute for Defense Analysis publication, *Cognitive Readiness: Preparing for the Unexpected,* Fletcher describes cognitive readiness as "mental preparation (including skills, knowledge, abilities, motivations, and personal dispositions) an individual needs to establish and sustain competent performance in the complex and unpredictable environment of modern military operations."[36] Cognitive readiness facilitates stress management for CNS neuroplasticity to optimize behavior, vice debilitative stress that undermines human performance. In this simple relationship that places the human brain at the center of information in and behavior out, cognitive readiness can only influence the cognitive analysis the brain executes. DoD leadership must be concerned with the variable set that re-enforces anticipated and appropriate cognitive analysis, in an effort to achieve cognitive readiness. Fletcher highlights 10 variables he considers as foundational to cognitive readiness. These variables are situational awareness, memory, transfer, meta-cognition, automaticity, problem solving, decision making, mental flexibility, leadership, and emotion.[37] This paper will not review each term, but for the purpose of clarity transfer is the ability to apply lessons learned from one scenario to another. Meta-cognition is thinking about one's own thinking processes. Automaticity refers to cognitive processes or physical action that require minimal focused attention. These variables are descriptors of the

military member’s cognitive state and the inherent or untrained traits they possess. Military personnel functioning in high-risk, high-speed, and potentially lethal operations must act based on a normal cognitive state and sound inherent capability. In addition, they must act in accordance with trained principles. The ten variables proposed by Fletcher can be consolidated and related to performance in the following model.



The two terms used to define the model are *Action* and *Training*. Action is defined as a willingness to act in response to environmental stimuli that demand behavior. The term willingness is a complex behavioral assessment. Many people act or do not act based on a deluge of information and their dynamic state of readiness. Referring back to the CNS model, the information arrow is composed of two variables, which are volume and speed. These variables play a decisive role in the willingness to act. In some situations, the speed of information and the

volume is too overwhelming for people to engage in responsive action. Training is defined as the execution of that behavior in accordance with experience, education, and previous training. Organizations, such as DoD, require behavior that is predictable and rational. Much of this behavior can be trained or practiced in simulators or model scenarios.

The model depicts four basic quadrants aligning the spectrum of *Action* and *Training*. The member that lacks the desire to act and is not or inappropriately trained is cognitively and physically disengaged. This individual is insignificant to DoD operations. Self-identification will likely eliminate this group of individuals from the DoD pipeline. The individuals that will not act, but are trained are cognitively disengaged. This individual is the most significant risk to DoD operations. As discussed, this is the member that may have a vulnerable CNS due to previous injury or increased stress load. The member that will act, but is not or inappropriately trained is physically disengaged. This member may be a risk to operations if their judgment or inexperience is obstructive, however, if transfer is optimized the inexperienced member may still execute the correct behavioral response. Lastly, the member that is willing to act and appropriately trained is cognitively ready and in optimal condition to execute the correct behavior based on the scenario presented. The concept of cognitive readiness is to place as many DoD members in this category as possible.

Discussion

The battlefield in the 21st Century has increased in operational complexity more so than in any other time in history of human warfare. Available battlefield technology has advanced to a point that a soldier, sailor, or Airmen killed on the battlefield is uncommon. Technology has advanced to a point that information processing, situational awareness, and 24/7 operations are

common. Technology has advanced to a point that weapons once relegated to the annals of science fiction are providing operational effects and new methods of biological exploitation are on the near horizon. Each of these developments is directly related to the exploitation of the CNS. The modern era of warfare is driving second order strategic public health effects that have been difficult to assess and resolve. Commanders are faced with public health and human biological issues that are generally discussed and evaluated in the halls of academic institutions, not battlefields and cockpits.

The pace of research investigating TBI is accelerating due to impact on cognitive strategic public health. The most important advancement is pre- and post-deployment assessment. Exams such ANAM, combined with other neurophysiological exams will assist healthcare providers in determining pre-clinical signs of TBI in soldiers that have experienced an explosive event. Post-deployment surveys and the Military Acute Concussion Evaluation are tools to determine severity of blast effects. However, individual response data, depending on administration method, time, and venue may be significantly skewed or simply incorrect. Promising research utilizing proteomics suggests the human can be "removed from the loop".[38] In this TBI animal-model study, serum was collected and examined utilizing high-throughput proteomic analysis. Experimental animals demonstrated elevated serum levels of corticosterone, glial fibrillary acidic protein, and vascular endothelial growth factor 2-months post injury. These are markers of CNS inflammation associated with the CNS damage. These data suggest diagnostics and post-deployment assessment that is independent of self-reporting, is not too far in the future. This type of diagnostic will lessen the impact of the TBI to strategic public health because instead of going untreated, TBI will be diagnosed and addressed. This level of diagnostic will also impact severity of undiagnosed/unreported PTSD.

Fatigue management research in the USAF has slowly ebbed as effective strategies have transitioned to the field. The Fatigue Assessment Scheduling Tool (FAST) developed by the AFRL in 2000-2001 is an excellent software-based planning tool that allows users to profile missions and implement recommendations for napping schedule and/or wakefulness management drugs. The US Army continues to evaluate the effectiveness of caffeine in operational scenarios, but is now largely examining more academic questions regarding dosage rather than operational efficacy.[39] Despite the ebb in DoD-level fatigue management research there are new questions constantly arising in operational scenarios that support the hypothesis that the CNS is vulnerable to extreme fatigue. An area that has received very little research assistance is the new mission set of full-motion video analysis provided by remotely-piloted aircraft. Operators are tasked to work 12 hour shifts, watching monotonous video to gather intelligence data, for the purpose of target acquisition. Thus, higher order CNS processing is required for attention, visual acuity, and decision-making. Higher-order function tends to be the first capability sacrificed in the fatigued CNS as reported by ANAM and PVT. Fatigue, boredom, and counter circadian rhythm operations all function in concert to decrease mission effectiveness through CNS over-utilization and task saturation. The CNS is still susceptible to fatigue and while traditional models have decreased the strategic public health implications, the CNS remains vulnerable to insult in new operational scenarios.

Lastly, advances in RF technology will drive a new set of CNS strategic public health challenges on modern battlefields. DoD leadership must be aware of the biological implications of enemy employment, but also our employment of RF weapons on the enemy. The Defense Science Board Task Force on Directed Energy Weapons has recommended DoD understand exactly what the risks are when using this class of non-lethal weapon and clearly determine if the

operational significance outweigh the risk.[40] A thorough understanding of the strategic public health and human biology will facilitate effective decision making. As RF exploitation moves beyond ADS and into technology that can exploit the CNS, DoD must have a very clear understanding of the capability of our own technology and the enemies technology. Cognitive disruption of the enemy is a very attractive capability to utilize before engaging the enemy. The US has publically been accused of pursuing rudimentary-levels of these techniques with Iraqi POWs.[41] In this *British Broadcasting Corporation* article, a US Psychological Ops representative discusses use of *Metallica* and music from the children's program *Barney* to degrade cognitive function for the purpose of extracting information. One may assume that as basic understanding of the molecular function of the CNS is elucidated; means to exploit the biology are being developed simultaneously.

Cognitive readiness is a re-emerging DoD focus area. The DoD Human Factors Engineering Technical Advisory Group is engaging research and industry communities to examine these concepts to better prepare DoD members.[42] The model presented in this paper consolidates the significant variables of cognitive readiness and frames with a focus on behavior. While cognitive readiness is designed to enhance and protect the function of the CNS, the measure of effectiveness is the behavioral response. There are still many other, more difficult to quantify, variables that underlie someone's desire to act. Many of these DoD experience cannot affect, including genetics, upbringing, and prior exposure to stressful or emergency scenarios. These variables directly influence how someone reacts to elevated stress levels. DoD can capitalize on someone's desire to act through experience and the inherent aspect of self-selection through exposure to these types of situations. Experience comes from exposure to situations, while on active duty, that require action. For most DoD personnel, this comes from deployments

to hostile locations. Despite the risk of loss of life, it is this valuable experience that DoD educators and trainers must rely on to develop its members. The DoD must better develop its educational and training methods while on deployment to develop cognitive readiness. The second variable, in accordance with training, is the dominant variable as DoD can influence this directly. While there is significant research into how to deliver training to develop cognitive readiness, the key component is a soldier, sailor, marine, or Airman that acts in accordance with that training.[43] Irrational and/or unpredictable action during operations indicates that individual is not cognitively prepared because the executed behavior is not in accordance with desired outcomes. DoD training and education models must focus on producing military members that have a willingness to act, act in accordance with experience, education, and training, and are resilient to the outcomes of that action.

In the model depicted, DoD trainers and educators strive to produce members that are well trained and willing to act effectively. This soldier, sailor, marine, and Airmen's CNS is cognitively prepared for operations and unencumbered by cognitive distractors. Significant questions remain regarding how the behavioral model is best used to predict or classify cognitive readiness of the DoD member. The key question is; can an individual's cognitive readiness change over time? This would be depicted in the model by a migration from one quadrant to another. Moreover, if DoD leadership seeks to maintain the cognitive readiness of its members, what is the viability of maintaining a member in a heightened state of cognitive readiness for long periods of time?

Regarding the first question concerning migration from one quadrant another, it is likely that a member may migrate among the quadrants of the model. The variable set that influences the spectrum of *Action* is significant. Some of these are directly associated with the operational

environment, while others exist in the personal life of the member. Migration from a high position in the action spectrum to a lower position on the action spectrum is inevitable as the stressors of combat increase. We know that physiological measures of performance decrease substantially due to sustained military operations.[44] Of course, physiological measures of performance can be brought back to optimal levels with sleep, nutrition, and removal from the operational environment. To conclude that cognitive readiness degrades with heightened operations tempo seems likely. However, are the solutions available for physiological recharge similar for cognitive readiness recharge? Additionally, as personal issues accumulate due to familial absenteeism associated with deployments, these issues begin to erode the likelihood of effective cognitive action. Other factors that negatively influence military member's willingness to act effectively include alcohol or substance behavior that tend to accompany repeated deployments involving high operations tempo and repeated exposures to the combat environment.[45]

Migration along the *Training* spectrum seems unlikely once training has been acquired. However, there have been hard lessons learned regarding what were thought to be similar counter insurgency (COIN) operations conducted by major military powers. In the largely successful COIN operations in Malaya and the Philippines, the military effort was dominant; routed in military doctrine.[46] However, in the COIN operations conducted in El Salvador political reform played a primary role, while military intervention was secondary. Furthermore, the Portuguese in Africa, French in Algeria, and Soviet Union in Afghanistan were all unsuccessful because they attempted to apply previous models of COIN operations to insurgencies that had unique sets of circumstances. These examples illustrate the point that military training, while designed to be dynamic and adaptable does not always fit the scenario.

Thus, while a military member may be well trained in a certain skill set the application of that skill to a new scenario may inadvertently push that member down the *Training* spectrum.

The second question regarding the ability of DoD members to maintain a cognitive readiness posture will require more research and a better understanding of the requirements to maintain soldiers, sailors, marines, and Airmen at a heightened status of readiness. The previous discussions have highlighted variables that will drive DoD members back down the *Action* and *Training* spectrum out of the quadrant DoD invests significant money, training, and education in. Until reliable measures of cognitive readiness can be developed, there is no real way to measure the optimum level and the subsequent decrement from that level that time, low operations tempo, high operations tempo, and family will cause.

The CNS is and will be the target of operations in the modern battlefield. Whether the insult is a consequence of the enemies operations or our own, thorough understanding of the cognitive public health risks of our soldiers, sailors, marines, and Airmen are necessary for DoD decision makers. As demonstrated in this article, the CNS is vital to military operations because DoD depends on its members to interpret information correctly and act in accordance with training and education. DoD researchers and operators alike must focus on protecting action that is predictable and rational. Strategies are emerging that are designed to better prepare DoD members for the insults to the CNS, this protecting effective action. The focus on cognitive readiness will hopefully move from the research community to the operational community to facilitate a more resilient CNS that executes effective behavior. Recent operational experiences in Iraq and Afghanistan have accelerated our research and development efforts, as well as, highlighted the concerns and problems that require research within DoD and civilian research

communities. These efforts will pay dividends in the safety and health of soldiers, sailors, marine, and Airmen.

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